U.S. FISH AND WILDLIFE SERVICE SPECIES ASSESSMENT AND LISTING PRIORITY ASSIGNMENT FORM

Scientific Name:

Lampsilis bracteata

Common Name:

Texas Fatmucket

Lead region:

Region 2 (Southwest Region)

Information current as of:

03/24/2015

Status/Action

___ Funding provided for a proposed rule. Assessment not updated.

___ Species Assessment - determined species did not meet the definition of the endangered or threatened under the Act and, therefore, was not elevated to the Candidate status.

___ New Candidate

_X_ Continuing Candidate

___ Candidate Removal

> ___ Taxon is more abundant or widespread than previously believed or not subject to the degree of threats sufficient to warrant issuance of a proposed listing or continuance of candidate status
>
> ___ Taxon not subject to the degree of threats sufficient to warrant issuance of a proposed listing or continuance of candidate status due, in part or totally, to conservation efforts that remove or reduce the threats to the species
>
> ___ Range is no longer a U.S. territory
>
> ___ Insufficient information exists on biological vulnerability and threats to support listing

___ Taxon mistakenly included in past notice of review

___ Taxon does not meet the definition of "species"

___ Taxon believed to be extinct

___ Conservation efforts have removed or reduced threats

___ More abundant than believed, diminished threats, or threats eliminated.

Petition Information

___ Non-Petitioned

_X_ Petitioned - Date petition received: 06/25/2007

90-Day Positive:12/15/2009

12 Month Positive:10/06/2011

Did the Petition request a reclassification? **No**

For Petitioned Candidate species:

Is the listing warranted(if yes, see summary threats below) **Yes**

To Date, has publication of the proposal to list been precluded by other higher priority listing? **Yes**

Explanation of why precluded:

Higher priority listing actions, including court-approved settlements, court-ordered and statutory deadlines for petition findings and listing determinations, emergency listing determinations, and responses to litigation, continue to preclude the proposed and final listing rules for this species. We continue to monitor populations and will change its status or implement an emergency listing if necessary. The Progress on Revising the Lists section of the current CNOR, (http://endangered.fws.gov/) provides information on listing actions taken during the last 12 months.

Historical States/Territories/Countries of Occurrence:

- **States/US Territories**:State(s) information not available
- **US Counties**:County information not available
- **Countries**:Country information not available

Current States/Counties/Territories/Countries of Occurrence:

- **States/US Territories**: Texas
- **US Counties**: Gillespie, TX, Gonzales, TX, Karnes, TX, Kerr, TX, Kimble, TX, Llano, TX, Mason, TX, Menard, TX, Runnels, TX, Tom Green, TX, Travis, TX
- **Countries**:Country information not available

Land Ownership:

Four of the known Texas fatmucket populations occur in State designated no-harvest sanctuaries including: sections of Live Oak Creek in Gillespie County, Guadalupe River in Kerr County, San Saba River in Menard County, and Elm Creek in Runnels County (Howells 2010c, p. 8). The remaining five populations occur in the Colorado or Guadalupe-San Antonio River systems adjacent to private land.

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Biological Information

Species Description:

The Texas fatmucket is a large, elongated mussel that reaches a maximum length of 100 millimeters (mm) (3.94 inches (in)) (Howells 2010c, p. 2). The shell is oval to elliptical or somewhat rhomboidal and tan to greenish-yellow with numerous irregular, wavy, and broad and narrow dark brown rays, with broad rays widening noticeably as they approach the ventral (underside) margin. The nacre (inside of the shell) is white with occasional yellow or salmon coloration and iridescent posteriorly (Howells 2010c, p. 2). Females have mantle flaps (extensions of the tissue that covers the visceral mass) that often resemble minnows, including eye spots, lateral line, and fins (Howells 2010c, p. 2).

Taxonomy:

The Texas fatmucket (Lampsilis bracteata) was first described in 1855 by Gould as Unio bracteatus and later moved to the genus Lampsilis by Simpson (1900, p. 543). Some forms found in headwater streams were historically split into a different species, L. elongatus, but they have since been determined to be L. bracteata that were ecophenotypes (individuals whose shape is determined by their environment) (Howells 2010c, p. 5). The Texas fatmucket is recognized by the Committee on Scientific and Vernacular Names of Mollusks of the Council of Systematic

Malacologists, American Malacological Union (Turgeon et al. 1998, p. 34), and we recognize it as a valid species.

Habitat/Life History:

The Texas fatmucket occurs in moderately sized rivers in mud, sand, or gravel, or mixtures of these substrates (Howells 2010c, p. 4) and sometimes in narrow crevices between bedrock slabs (Howells 1995, p. 21). Live individuals have been found in relatively shallow water, rarely more than 1.5 meters (m) (4.9 feet (ft)) deep, and usually less. Remaining populations typically occur at sites where one or both banks are relatively low, allowing floodwaters to spread out over land and thereby reducing damage from scouring (Howells 2010c, p. 4). Burlakova and Karatayev (2012b, p. 16) conducted a habitat analysis based on recent survey findings, which found that Texas fatmucket typically favored rivers with bedrock characterized by very low water capacity and rapid water permeability that quickly dry during low water and drought events. This is why Texas fatmucket are especially prone to the changes in water regime and water over-extraction (Burlakova and Karatayev 2012b, p. 16).

It was once thought that this species was intolerant of impounded waters, man-made or natural. However, surveys in 2012 and 2013 conducted by the U. S. Fish and Wildlife Service (Service), U.S. Geological Surveys (USGS), and Texas Parks and Wildlife Department (TPWD) suggest that Texas fatmucket typically occurs in quiet, slow moving waters in fine silt substrate along the perimeter of impounded waters and in rivers near macrophyte (aquatic plant) growths of which the majority of the water body is made up of bedrock with pool habitat (Service files 2012; 2013).

Although there is no specific information on age and size of maturity of the Texas fatmucket, it is likely similar to a related species, the Louisiana fatmucket (L. hydiana), which reaches sexual maturity around 36 mm (1.4 in) (Howells 2000b, pp. 35–48; Howells 2010c, p. 3). Texas fatmucket females have been found gravid (with glochidia in the gill pouch) from July through October, although brooding may continue throughout much of the year (Howells 2010c, p. 3). Texas fatmucket females display a mantle lure to attract host fish, releasing glochidia when the lure is bitten or struck by the fish. Bluegill (Lepomis macrochirus) and green sunfish (L. cyanellus) have been successful hosts in laboratory studies (Howells 1997b, p. 257). Recent host fish study conducted by USGS and the Service reconfirmed bluegill as one of its primary host fish (Johnson et al. 2014, p. 46). Hosts such as these sunfishes are common, widely distributed species in Texas that occur in an array of habitat types (Hubbs et al. 2008, p. 45) and would not generally be expected to be a limiting factor in Texas fatmucket reproduction and distribution (Howells 2010c, p. 3).

Adult freshwater mussels are filter-feeders, siphoning algae, bacteria, detritus, microscopic animals, and dissolved organic matter (Fuller 1974, pp. 221–222, Silverman et al. 1997, p. 1862; Nichols and Garling 2000, p. 874–876; Christian et al. 2004, p. 109). For their first several months, juvenile mussels feed using cilia (fine hairs) on the foot to capture suspended as well as depositional material, such as algae and detritus (Yeager et al. 1994, pp. 253–259). Mussels tend to grow relatively rapidly for the first few years, and then slow appreciably at sexual maturity, when energy presumably is being diverted from growth to reproductive activities (Baird 2000, pp. 66–67). Mussels are extremely long lived, living from two to several decades (Rogers et al. 2001, p. 592), and possibly up to 200 years in extreme instances (Bauer 1992, p. 427).

Most mussel species, including Texas fatmucket, have distinct forms of male and female. During reproduction, males release sperm into the water column, which females draw in through their siphons. Fertilization takes place internally, and the resulting eggs develop into specialized larvae (called glochidia) within the female's modified gill pouch (called marsupia) for 4 to 6 weeks. The females will then release matured glochidia individually, in small groups, or embedded in larger mucus structures called conglutinates. Glochidia are obligate parasites (cannot live independently of their hosts) on fish and attach to the gills or fins of appropriate host species where they encyst (enclose in a cyst-like structure) and feed off of the host's body fluids (Vaughn and Taylor 1999, p. 913) and develop into juvenile mussels weeks or months after attachment (Arey 1932, pp. 214–215). The glochidia will die if they fail to find the appropriate host fish, attach to a fish that has developed immunity from prior infestations, or attach to the wrong location on a host fish (Neves 1991, p. 254; Bogan 1993, p. 299). Mussels experience their primary opportunity for dispersal and movement within the stream as glochidia attached to a host fish (Smith 1985, p. 105). Upon release from the host, newly transformed juveniles drop to the substrate on the bottom of the stream. Those juveniles that drop in unsuitable substrates die because their immobility prevents them from relocating to more favorable habitat. Juvenile freshwater mussels burrow into interstitial substrates and grow to a larger size that is less susceptible to predation and displacement from high flow events (Yeager et al. 1994, p. 220). Throughout the rest of their life cycle, mussels generally remain within the same small area where they released from the host fish.

Historical Range/Distribution:

The Texas fatmucket historically had populations in at least 18 rivers in the upper Colorado, Guadalupe, and San Antonio River systems in the Texas Hill Country and east-central Edwards Plateau region of central Texas. In the Colorado River, it ranged from Travis County upstream approximately 320 kilometers (km) (200 miles (mi)) to Runnels County. It was also found in many tributaries of the Colorado River, including the Pedernales, Llano, San Saba, and Concho Rivers, and Jim Ned, Elm, and Onion Creeks (Howells et al. 1996, p. 61). In the Guadalupe-San Antonio River basin, the Texas fatmucket occupied approximately 240 km (150 mi) of the Guadalupe River, from Gonzales County upstream to Kerr County, including the North Guadalupe River, Johnson Creek, and the Blanco River. In the San Antonio River, it ranged from its confluence with the Medina River in Bexar County upstream to the City of San Antonio, as well as in the Medina River and Cibolo Creek (Howells et al. 1996, p. 61; Howells 2010c, p. 6).

Strecker (1931, pp. 66–68) reported Texas fatmucket from a lake in Victoria County in the lower Guadalupe River drainage (Howells 2010c, p. 6), but this is probably a misidentified Louisiana fatmucket, which occurs in lakes or impoundments. A Salado Creek record from Bell County (Strecker 1931, pp. 62–63) is also probably a misidentified Louisiana fatmucket, since the Texas fatmucket is not known to occur in the Brazos River basin or its western tributaries (Howells et al. 1996, p. 61; Howells 2010c, p. 6).

Current Range Distribution:

The Texas fatmucket has declined significantly range wide and is now known from only nine streams in the Colorado and Guadalupe River systems in very limited numbers. Most existing populations are represented by only one or two individuals and are likely not stable or recruiting (juvenile mussels joining the adult population). In the streams where the species is extant (surviving), populations are highly fragmented and restricted to short reaches with few exceptions. The Texas fatmucket has been considered a species of special concern by some malacologists for several decades (Athearn 1970, p. 28).

Colorado River System

The Texas fatmucket was historically known to occur throughout the Colorado River and numerous tributaries (Randklev et al. 2010c, p. 4). However, in the mainstem Colorado River, the Texas fatmucket has not been found, live or dead, in several decades despite numerous surveys (Howells 1994, p. 4; 1995, pp. 20–21, 25, 29; 1996, pp. 20, 23; 1997a, pp. 27, 31, 34–35; 1998, p. 10; 1999, p. 18; 2000a, pp. 25–27; 2002a, pp. 6–7; 2004, pp. 7, 10–11; 2005, p. 6; Johnson 2009, p. 1; Burlakova and Karatayev 2010a, p. 12), and thus is considered extirpated (eliminated from) from the Colorado River mainstem. Within the remainder of this system, the species is only known from sparse populations in Colorado River tributaries, including the South Concho River, Spring Creek, Llano River (including Threadgill Creek), Pedernales River (including Live Oak Creek), Onion Creek, Jim Ned Creek, Elm Creek, and the San Saba River.

Evidence of persisting Texas fatmucket populations has been found in Spring Creek, a tributary to the Middle Concho River, which flows into the Concho River, a large tributary of the Colorado River. Historically, Spring Creek harbored Texas fatmucket in Iron and Tom Green Counties (Randklev et al. 2010c, p. 1). In 1993, discovery of shell material prompted additional surveys, and in 1997, one live individual was found in Irion County (Howells 1998, p. 13). Farther downstream, in Tom Green County, two live individuals were recorded in 1997, upstream of Twin Buttes Reservoir (Howells 1998, pp. 13–14), but no evidence of the Spring Creek population was found in 2008 (Burlakova and Karatayev 2010a, p. 12). Further, Spring Creek was reported to have dried in 1999 and 2000, which may have eliminated the population there (Howells et al. 2003, p. 5).

In the Llano River, there are three areas that are currently known to contain Texas fatmucket populations. The species occurred throughout the length of the river historically (Ohio State University Museum (OSUM) 2011a, p. 1). A single shell was collected in Llano County in 1992 (Howells 1994, p. 6), and eight live individuals were found in 2011 (Burlakova and Karatayev 2011, p. 1). Individuals were small in size, indicating a potentially reproducing population. The species also persists in Mason County, where two shell fragments of recently dead Texas fatmucket were found in 1995 (Howells 1996, p. 22), and two live individuals were collected at the same site in 2009 (Burlakova and Karatayev 2010a, pp. 12–13). The species also appears to persist in Kimble County, where one live Texas fatmucket was recorded in 2009 (Burlakova and Karatayev 2010a, pp. 12–13). In addition, the Service and USGS found several fresh dead to recently dead shells during presence/absence surveys at this site in 2012 (Service Files, 2012).

In 2004, four live Texas fatmucket were recorded from Threadgill Creek, a tributary to the Llano River in Gillespie and Mason Counties (Howells 2005, pp. 6–7). This population is on private land, which limits survey access, but Howells (2009, p. 5) indicates it likely persists due to favorable land management.

Live Oak Creek, a tributary to the Pedernales River in Gillespie County, also contains a sparse Texas fatmucket population. In 2002, 11 shells were discovered, and in 2003, one live individual was recorded, confirming the species persisted in low numbers (Howells 2003, p. 10; Howells 2004, pp. 8–9). Since that time, surveys have been conducted in Live Oak Creek on a fairly regular basis. The stream was visited on two different occasions in 2004, with only shell material found (Howells 2005, pp. 7–8), and again in 2005, when two live individuals were recorded (Burlakova and Karatayev 2010a, p. 12). The stream was surveyed in 2007 and 2008, but no evidence of the species was found (Howells 2009, p. 5). However, in 2011, one live and three recently dead valves were found (Howell 2012, pers. comm.), and further downstream of this site five live individuals were found (Randklev 2012, pers. comm.). This population is presumed to be small but persisting.

In the Pedernales River mainstem, survey efforts in the 1990s yielded only old shell material (Howells 1994, p. 4; OSUM 2011a, p. 1; Howells 1995, p. 28; Howells 1999, p. 16). However, in 2011, a live individual was observed in Gillespie County (Randklev 2012) and in 2012 and 2013, several recent dead shells were collected at the same site and at an additional site downstream (Service Files, 2013). Further downstream in Hays County a single live individual was located in 2011 (May 2012, pers. comm.). It is apparent that small populations may persist in isolated pockets throughout the Pedernales River mainstem.

Records of speckled pocketbook (Lampsilis streckeri) from Onion Creek in Travis County in 1931 are now believed to have been misidentified; instead, they represent records of Texas fatmucket (Howells 2010c, p. 6; Randklev et al. 2010c, p. 4). The stream was surveyed in 1993, and no live freshwater mussels were found (Howells 1995, p. 28). However, in 2010, three live Texas fatmucket were found near Highway 71 (Wilkins et al. 2010, pp. 10), indicating the species persists there. Presence/absence surveys in this area during May 2012 failed to locate any live or spent valves of Texas fatmucket. However, one recent dead shell was collected downstream from this site in 2012 (Service Files, 2012).

Elm Creek, a tributary to the Colorado River, has been known to harbor a Texas fatmucket population since 1993, when 10 live individuals were recorded (Howells 1995, p. 21). Since that time, the population has declined, with two individuals found in 1995 (Howells 1996, pp. 19–20), and no live individuals found in 2001 or 2005 (Howells 2002a, p. 5; 2006, p. 63). In 2008, additional sites downstream of the known population were surveyed and one live individual was recorded after 15 person-hours of searching (Burlakova and Karatayev 2010a, p. 12), indicating that the species continues to persist in Elm Creek, although in very low numbers.

Texas fatmucket continue to persist in isolated pockets in the upper San Saba River throughout Menard County, where the species has been known to occur historically (Randklev et al. 2010c, p. 2; OSUM 2011a, p. 1). In 1997, three live individuals were found (Howells 1998, p. 16); however, in 2000 and 2004, none were located (Howells 2001, p. 29; Howells 2005, pp. 8–9). One live individual was found in 2005 (Howells 2006, p. 64), and one recent dead shell in 2008 (Burlakova and Karatayev 2010a, p. 12). In July 2011, 12 live Texas fatmucket were found west of Menard in Menard County (Burlakova and Karatayev 2012a, p.3; Burlakova and Karatayev 2012b, p. 14). Later in 2011, 30 live individuals were located during survey efforts (Randklev 2012). The Service and USGS located six live individuals, including females displaying their mantels, and several recently dead individuals in the same area in 2012 (Service Files, 2012). Surveys conducted further downstream in 2013 found four live individuals and recent dead shells (Service Files 2013). In 2011, Burlakova and Karatayev (2012a, p. 3; 2012b, p. 14) visited the middle part of the San Saba River northeast of Hext, Menard County, Texas and found that the river bed was dry with few pools of water left. They found a total of 65 very recently dead mussels during their 2011 survey efforts of this stretch of river (Burlakova and Karatayev 2012a, p.3; Burlakova and Karatayev 2012b, p. 14). Using Texas fatmucket densities in the upper and middle San Saba River, Burlakova and Karatayev (2012b, p. 14) calculated that total size of the population in the river was 8,000 to 10,000 mussels in 2011. However, a large part of the population may have not survived the 2011-2012 droughts (Burlakova and Karatayev 2012b, p. 15).

The Texas fatmucket is considered extirpated from the South Concho River and Jim Ned Creek. In the South Concho River, old Texas fatmucket shell fragments were found in gravel bars in Tom Green County in 1997, but there has been no additional evidence of the species (Howells 1998, p. 12). Additionally, three live individuals were recorded from Jim Ned Creek in Brown County in 1979 (Randklev et al. 2010c, p. 3), but the species has not been found in this stream since then (Howells 1997a, pp. 29–30).

Guadalupe River System

While the Texas fatmucket was never widely distributed in the Guadalupe River system, the only remaining populations are in the mainstem of the upper Guadalupe River and possibly the North Fork Guadalupe River. It is presumed extirpated from the entire San Antonio River system, as well as the Blanco River and Johnson Creek.

In the mainstem upper Guadalupe River, the Texas fatmucket historically and currently occurs in Kerr County (OSUM 2011a, p. 1). In 1996, two live individuals were recorded in Kerr County below the Upper Guadalupe River Authority(UGRA) dam in Kerrville, Texas (Howells 1997a, p. 36), and in 1997, three shells were found at the same site following a flood (Howells 1998, p. 18). No live individuals have been located below the UGRA dam since the initial discovery of the two flood deposited specimens in 1997.

Howells (2011, pers. comm.) found five live and 28 very recently dead to long dead shells in a reservoir created by the UGRA dam in Kerr County in 2011. He initially thought all specimens found live in this area and just below the dam were flood deposited, but later changed his mind when he discovered several live and dead individuals at various age classes, which suggest that this species is capable of tolerating impounded waters (Howells 2011, pers. comm.). Immediately downstream from the UGRA dam, in a smaller reservoir, created by a low head dam, the Service and TPWD located live Texas fatmucket in 2013 during a presence/absence survey (Service Files 2013). The survey efforts were extended downstream from the low head dam in 2012 and 2013 in Kerr County where only recent dead shells and no live individuals were found (Service Files, 2012; Service Files, 2013). Based on recent findings it is presumed small populations of Texas fatmucket occur within the reservoirs in Kerr County, which would be the first official record of Texas fatmucket occurring within a reservoir.

In 1998, 20 recently dead individuals were discovered approximately 1 km (0.6 mi) downstream of UGRA in Louise Hayes Park during a drawdown (Howells 1999, pp. 18–19), and 6 live individuals were found at the same location in 2005 (Howells 2006, pp. 71–72). Surveys in 2007, 2008, and 2012 yielded no live or recently dead individuals (Burlakova and Karatayev 2010a, p. 12; Service Files, 2012). It is likely that the species persists in the vicinity but in very low numbers. There has been no other evidence of Texas fatmucket in the mainstem Guadalupe River in recent years.

In 1999, two recently dead Texas fatmucket were found in North Fork Guadalupe River (Howells 2000a, p. 27). This river was surveyed again in 2000 and 2003 at several sites, and no Texas fatmucket were found (Howells 2001, p. 31; Howells 2004, pp. 13–14).

Johnson Creek was a historical location for Texas fatmucket, but no live freshwater mussels of any species have been found in this stream for decades (Howells 1996, p. 25; Howells 1998, p. 18; Howells 2002a, p. 8). Additionally, the Blanco River has been surveyed extensively since 1992, and no evidence of Texas fatmucket has been collected, nor is suitable habitat present (Howells 1994, p. 9; Howells 1995, pp. 32–33; Howells 1996, p. 28; Johnson 2011, p. 1). The last collection of Texas fatmucket from the Blanco River occurred in the 1970s or 1980s (Howells 2005, p. 10).

Texas fatmucket have also been extirpated from the entire San Antonio River system. The mainstem San Antonio River was surveyed in 1993 and 1996, and no live or dead Texas fatmucket were found (Howells 1995, p. 35; 1997a, pp. 41–42). No live or dead individuals were found in 2011 within a four mile section of the lower San Antonio River from Bexar County to Goliad County (Larralde 2011, pp. 18). It was known from the Medina River, a tributary to the San Antonio River, historically (Randklev et al. 2010c, p. 3), but no mussels of any species have been found in this river in recent years (May 2011, pers. comm.). Additionally, although Texas fatmucket were collected from Cibolo Creek historically (OSUM 2011a, p. 1) and shell material, likely from Texas fatmucket, was found in 1993 (Howells 1995, p. 36), no live freshwater mussels have been found in Cibolo Creek since (Howells 1997a, pp. 40–41).

Population Estimates/Status:

Based on historical and current data, the Texas fatmucket has declined significantly rangewide and has been extirpated from most of the Guadalupe River system and hundreds of miles of the Colorado River, as well as from numerous tributaries. Extant populations are represented by only a few individuals, and they are highly disjunct and restricted to short reaches. Two of the sites known to harbor Texas fatmucket in recent years may no longer support this species, and the remaining seven sites harbor few individuals and are likely not stable. No evidence of recent recruitment has been found in any of the sites, with the possible exception of the Llano River.

Threats

A. The present or threatened destruction, modification, or curtailment of its habitat or range:

The decline of mussels in Texas and across the United States is primarily the result of habitat loss and degradation (Neves 1991, pp. 252, 265; Howells et al. 1996, pp. 21–22). Chief among the causes of mussel decline in Texas are the effects of impoundments, sedimentation, dewatering, sand and gravel mining, and chemical contaminants (Neck 1982a, pp. 33–35; Howells et al. 1996, pp. 21–22; Winemiller et al. pp. 17–18). These threats are discussed below.

Impoundments
A major factor in the decline of freshwater mussels across the United States has been the large-scale impoundment of rivers (Vaughn and Taylor 1999, p. 913). Dams are the source of numerous threats to freshwater mussels: They block upstream and downstream movement of species by blocking host fish movement; they eliminate or reduce river flow within impounded areas, thereby trapping silts and causing sediment deposition; and dams change downstream

water flow timing and temperature, decrease habitat heterogeneity, and affect normal flood patterns (Layzer et al. 1993, pp. 68–69; Neves et al. 1997, pp. 63–64; Watters 2000, pp. 261–264; Watters 1996, p. 80). Within reservoirs (the impounded waters behind dams), the decline of freshwater mussels has been attributed to sedimentation, decreased dissolved oxygen, and alteration of resident fish populations (Neves et al. 1997, pp. 63–64; Pringle et al. 2000, pp. 810–815; Watters 2000, pp. 261–264). Dams significantly alter downstream water quality and stream habitats (Allan and Flecker 1993, p. 36; Collier et al. 1996, pp. 1, 7) resulting in negative effects to tailwater (the area downstream of a dam) mussel populations (Layzer et al. 1993, p. 69; Neves et al. 1997, p. 63; Watters 2000, pp. 265–266). Below dams, mussel declines are associated with changes and fluctuation in flow regime, scouring and erosion of stream channels, reduced dissolved oxygen levels and water temperatures, and changes in resident fish assemblages (Williams et al. 1992, p. 7; Layzer et al. 1993, p. 69; Neves et al. 1997, pp. 63–64; Pringle et al. 2000, pp. 810–815; Watters 2000, pp. 265–266). Numerous dams have been constructed throughout the Colorado and Guadalupe-San Antonio River systems within the range of Texas fatmucket (Stanley et al. 1990, p. 61).

Population losses due to the effects of dams and impoundments have likely contributed more to the loss of diversity and abundance of freshwater mussels across Texas, including Texas fatmucket, than any other factor. Stream habitat throughout nearly all of the range of Texas fatmucket has been affected by numerous impoundments, leaving generally short, isolated patches of remnant habitat between dams. Impoundments have resulted in profound changes to the nature of the rivers, primarily replacing free-flowing river systems with a series of large reservoirs.

There are no natural lakes within the range of the Texas fatmucket, nor had it been found in reservoirs until recently. Surveys of the reservoirs on the Guadalupe and Colorado Rivers have been ongoing since at least 1992, and no evidence of live or dead Texas fatmucket had been found in any reservoir (Howells 1994, pp. 1–20; 1995, pp. 1–50; 1996, pp. 1–45; 1997a, pp. 1–58; 1998, pp. 1–30; 1999, pp. 1–34; 2000a, pp. 1–56; 2001, pp. 1–50; 2002a, pp. 1–28; 2003, pp. 1–42; 2004, pp. 1–48; 2005, pp. 1–23; 2006, pp. 1–106; Karatayev and Burlakova 2008, pp. 1–47; Burlakova and Karatayev 2010a, pp. 1–30; 2011, pp. 1–8). However, in 2011 and 2013, live Texas fatmucket were found in two impoundments in Kerr County, suggesting that this species is able to tolerate impounded waters, provided their preferred habitat is present (Howells 2011, pers. comm.; Service Files 2013). Impoundments occur throughout the range of the Texas fatmucket. The majority of the Nueces-Frio, Guadalupe, San Antonio, Colorado, and Brazos Rivers, as well as many tributaries, are now impounded. There are 31 major reservoirs within the Colorado River basin, with another reservoir (Goldthwaite Reservoir) being considered on the Colorado River in Mills and San Saba Counties; this reservoir was the number one recommendation in the water plan for the region (Texas Water Development Board (TWDB) 2011, p. 4–85). There are 29 reservoirs throughout the Guadalupe River basin and 34 reservoirs throughout the San Antonio River basin, each with a storage capacity of 3000 acre-feet or more, and many smaller reservoirs (Exelon 2010, p. 2.3–4). The majority of the large dams were constructed for power generation, flood control, and water supply, primarily by the Lower Colorado River and Guadalupe-Blanco River Authorities, beginning in the early twentieth century (Guadalupe-Blanco River Authority 2011, p. 1; Lower Colorado River Authority (LCRA) 2011a, p. 1). These, and numerous smaller dams, occur throughout the Colorado and Guadalupe River basins and have resulted in ongoing destruction and modification of Texas fatmucket habitat and the curtailment of its range.

Dams threaten freshwater mussels in several ways. First, they can prevent the movement of freshwater mussel host fish. The overall distribution of mussels is a function of the dispersal of their hosts (Watters 1996, p. 83). For example, Watters (1996, p. 80) found that the distributions of the fragile papershell (Leptodea fragilis) and pink heelsplitter (Potamilus alatus) in five midwestern rivers were determined by the presence of low-head dams. These dams were non-navigable (without locks), lacked fish ladders, and varied in height from 1 to 17.7 m (3 to 58 ft), and the host fish could not disperse through them. Although the distribution of mussels may depend on many ecological factors, the evidence presented in Watters (1996, pp. 79–85) illustrates that dams as small as 1 m (3 ft) high can limit the distribution of mussels. There are many dams that occur throughout the range of the Texas fatmucket that lack fish ladders and may be a barrier to the movement of fish hosts and, therefore, the distribution of mussels. Because the Texas fatmucket populations are all separated by dams of various sizes that are not passable by fish, the mussel is unable to disperse from its current occupied range through host fish migration.

Dams also alter aquatic habitat within the resulting impoundments. It is well documented that many mussel species that are adapted to flowing water stream environments do poorly in the altered aquatic conditions found within impoundments (Williams et al. 1992, p. 7; Vaughn and Taylor 1999, p. 913). Once a dam is constructed, the original river channel upstream remains intact but under much deeper water with much lower velocities. As water velocity decreases, water loses its ability to carry sediment; sediment falls to the substrate, eventually smothering mussels that cannot adapt to soft substrates (Watters 2000, p. 263). Over time, the original mussel species composition of the stream channel may be eliminated or changed in favor of silt tolerant species (Watters 2000, p. 264). The mussel community may be altered from one with many different species to a community dominated by one to several very common species (Neck 1982b, p. 174). Texas fatmucket most likely does not occur in large scale reservoirs, indicating it is not tolerant of lentic conditions, and it is now extirpated from impounded areas where it occurred prior to inundation. However, recent findings suggest that this species is somewhat tolerant of impounded waters provided adequate water flow and suitable substrate and habitat is still present. The inundation of stream habitat by impoundments is a likely cause of the reduction in the distribution of the Texas fatmucket. The presence of the impoundments has caused the permanent loss of Texas fatmucket habitat throughout its range.

The loss of seven freshwater mussel species native to Texas, including Texas fatmucket and golden orb, due to impoundment construction was documented on the Medina River (Neck 1989, p. 323). The Medina River was impounded in 1913 by construction of Medina Dam, and now only three different species of mussels, all of which are tolerant of lentic habitats (still waters such as lakes or ponds), occur in the impounded area. The bottom of Medina Lake now consists of moderate and steep limestone slopes and excessive silt deposits, whereas before it was most likely made up of a combination of silt, sand, and gravel substrates. Most mussels native to the Medina River were unable to adapt to the change in flowing water and substrate conditions (Neck 1989, p. 323), including the Texas fatmucket, which is no longer found in the river.

Mussels downstream of impoundments are often affected through changes in fish host availability, water quality (particularly lower water temperatures), habitat structure, and stream channel scouring (Vaughn and Taylor 1999, p. 916). The release of cold water from the hypolimnion (deeper and colder layer of water in reservoirs) can decrease the occurrence of fish species adapted to warm water and increase the occurrence of fish species adapted to colder water (Edwards 1978, pp. 73–75). This changes the species composition of suitable host fish and may prevent mussels from completing an essential part of their reproductive cycle. This has been demonstrated by the extirpation of mussel species from several rivers on the eastern seaboard of the United States, which has been linked to the disappearance of appropriate host fish; the reintroduction of the host fish to rivers has enabled mussel species to recolonize areas (Kat and Davis 1984, p. 174). In addition, because mussel reproduction is temperature dependent (Watters and O'Dee 1999, pp. 455–456), it is likely that individual mussels living in cold waters downstream of dam releases may reproduce less frequently, if at all (Layzer et al. 1993, p. 69). Low water temperatures can also significantly delay or prevent metamorphosis and glochidial release, which is often triggered by water temperature (Watters and O'Dee 1999, pp. 454–455; Watters and O'Dee 2000, p. 136).

Similar changes in water temperatures downstream of dams may be responsible for the loss of some Texas fatmucket populations. For example, Canyon Reservoir on the Guadalupe River in Comal County is a deep impoundment built in 1964 that has hypolimnetic water releases. Temperature monitoring stations throughout the Guadalupe River basin show that maximum temperatures above Canyon Reservoir averaged 29.6 degrees Celsius (°C) (85.3 degrees Fahrenheit (°F)); the maximum stream temperatures below the reservoir averaged only 19.7 °C (67.5 °F) (Edwards 1978, p. 72). After impoundment, dissolved oxygen and water temperature dropped, with an accompanying drop in mussel numbers and species diversity (Young et al. 1976, p. 216). According to historical museum records analyzed by Randklev et al. (2010b, pp. 1–32), the Texas fatmucket once occurred in this area of the Guadalupe River prior to the construction of Canyon Reservoir. The Guadalupe River and Canyon Lake in Comal and Kendall Counties were surveyed in 2009, and no live or recently dead Texas fatmucket were found (Burlakova and Karatayev 2010a, pp. 12–13). We reasonably conclude that the loss of the Texas fatmucket from this area was caused by the changes to the aquatic habitat of the Guadalupe River from the effects of Canyon Reservoir. Many of the dams throughout the range of Texas fatmucket have hypolimnetic water releases, including Canyon Reservoir on the Guadalupe River (Magnelia 2001, p. 1), and Inks Lake, Lake LBJ (Schnoor and Fruh 1979, p. 506), and Lake Travis (Texas Natural Resource Conservation Commission 2001, p. 4) on the Colorado River, among others. We anticipate that changes in water temperatures from water released by these and other reservoirs also alter mussel habitats in streams, causing the elimination of mussel populations downstream.

In addition to the temperature of water released from dams, highly fluctuating, turbulent tailwaters devoid of sediment will scour the riverbed downstream of dams, rendering the area without mussel habitat (Layzer et al. 1993, p. 69). Depending on the use of the dam, water levels may fluctuate on a regular interval (for hydroelectric purposes) or at random (for flood control) (Watters 2000, p. 265). On the Colorado River, Inks Lake, Lake Marble Falls, Lake Buchanan, Lake Austin, Lake Travis, and Lady Bird Lake are each used for one or both of these purposes. Mortality of another rare mussel species in Texas, the Texas heelsplitter (Potamilus amphichaenus) was attributed to scheduled dewatering of the Neches River below B.A. Steinhagen Reservoir in east Texas (Neck and Howells 1994, p. 15).

Fluctuating water levels below dams also result in dramatic changes in water velocity. Downstream of Lake Livingston on the Trinity River in east Texas, for example, high-volume water discharges and abrupt stoppages of flow resulted in a river bed composed of large rocks and shifting sand (Neck and Howells 1994, p. 14); these kinds of habitat changes would be inhospitable to Texas fatmucket below the dams within its range. In some rivers this unstable zone may be extensive. For example, the Brazos River downstream of Possum Kingdom Reservoir in Texas exhibited unstable substrate for 150 km (240 mi) below the dam (Yeager 1993, p. 68).
In one study of the downstream effects of dams, Vaughn and Taylor (1999, p. 915) found a strong, gradual, linear increase in mussel species richness and abundance at sites on the Little River in Oklahoma downstream from Pine Creek Reservoir. Their research revealed that mussel species richness and total abundance did not begin to rebound until 20 km (12 mi) downstream of the impoundment and did not peak until 53 km (33 mi) downstream. They noted the most obvious difference since reservoir construction has been the alteration of the flow and temperature regimes, which gradually return to preimpoundment levels with downstream distance from the dam. These alterations appear to have produced an extinction gradient of mussels that is most severe near the dam (Vaughn and Taylor 1999, p. 915). We expect similar effects on the Texas fatmucket and other Texas mussels downstream of dams.

Dam construction also fragments the range of Texas fatmucket, leaving remaining habitats and populations isolated by the structures as well as by extensive areas of deep uninhabitable, impounded waters. These isolated populations are unable to naturally recolonize suitable habitat that may be impacted by temporary but devastating events, such as severe drought, floods, or pollution. Dams impound river habitats throughout almost the entire range of the species, and these impoundments have left short and isolated patches of remnant habitat, typically between impounded reaches.

In summary, the widespread construction of dams has affected the Texas fatmucket throughout its range by significantly altering stream habitat both upstream and downstream of the dams by changing fish assemblages, water depths and velocities, water temperature, dissolved oxygen, substrate, and stream channels. The effects of dams are ongoing and continue to negatively impact the Texas fatmucket rangewide. Because of this loss of habitat and its effects on the populations, we find that the effects of impoundments are a threat to the Texas fatmucket.

Sedimentation

Siltation and general sediment runoff is a pervasive problem in streams and has been implicated in the decline of stream mussel populations (Ellis 1936, pp. 39–40; Vannote and Minshall 1982, p. 4105; Dennis 1984, p. ii; Brim Box and Mossa 1999, p. 99; Fraley and Ahlstedt 2000, pp. 193–194). Specific biological effects on mussels from excessive sediment include reduced feeding and respiratory efficiency from clogged gills (Ellis 1936, p. 40), disrupted metabolic processes, reduced growth rates, increased substrate instability, limited burrowing activity (Marking and Bills 1979, pp. 208–209; Vannote and Minshall 1982, p. 4106), physical smothering, and disrupted host fish attractant mechanisms (Hartfield and Hartfield 1996, p. 373). The primary effects of excess sediment on mussels are sublethal, with detrimental effects not immediately apparent (Brim Box and Mossa 1999, p. 101).

The physical effects of sediment on mussel habitats are multifold and include changes in suspended material load; changes in streambed sediment composition from increased sediment production and runoff in the watershed; changes in the form, position, and stability of stream channels; changes in water depth or the width-to-depth ratio, which affects light penetration and flow regime; actively aggrading (filling) or degrading (scouring) channels; and changes in channel position that may leave mussels stranded (Brim Box and Mossa 1999, pp. 109–112).

Increased sedimentation and siltation may explain, in part, why Texas fatmucket appear to be experiencing recruitment failure in some streams. Interstitial spaces (small openings between rocks and gravels) in the substrate provide essential habitat for juvenile mussels. When clogged with sand or silt, interstitial flow rates and spaces may become reduced (Brim Box and Mossa 1999, p. 100), thus reducing juvenile habitat availability. Juvenile freshwater mussels, including Texas fatmucket juveniles, burrow into interstitial substrates, making it particularly susceptible to degradation of this habitat.

Even in 1959, Colorado River was noted as having high sedimentation rates from agricultural activities (Soil Conservation Service 1959, pp. 56, 59). Approximately 40 percent of U.S. river miles do not meet Clean Water Act standards due to excessive sediment loads (Environmental Protection Agency (EPA) 2000, p. 1), with agricultural activities being the primary source of sediment in streams (Waters 1995, p. 170). In general, sedimentation, resulting from unrestricted access by livestock, has been shown to be a significant threat to many streams and their mussel populations (Fraley and Ahlstedt 2000, p. 193). A primary land use throughout the range of the Texas fatmucket is grazing by cattle, sheep, and goats (Hersh 2007, p. 11). Soil compaction, which reduces vegetative growth, from intensive grazing, may reduce infiltration rates and increase runoff and erosion, and trampling of riparian vegetation increases the probability of erosion (Armour et al. 1994, p.10; Brim Box and Mossa 1999, p. 103).

Another cause of increased sediments in streams is widespread brush removal, such as that of the native plant, Juniperus ashei (Ashe juniper), throughout central Texas. Juniperus ashei removal can cause a marked increase in sediment runoff into streams (Greer 2005, p. 76). The Texas State Soil and Water Conservation Board has a funding program specifically for Juniperus ashei removal in Blanco, Gillespie, Kerr, Kendall, and Travis Counties (Gillespie County Soil and Water Conservation District 2011, p. 1), which includes the watersheds of three known Texas fatmucket populations in Live Oak Creek, Threadgill Creek, and the upper Guadalupe River. In one example, Howells (2010f, p. 6) noted increased sediment deposition after widespread Juniperus ashei removal upstream of the Texas fatmucket population in Live Oak Creek.

Sedimentation may become an increasing threat to the Texas fatmucket in the Colorado and Guadalupe River basins as the Austin and San Antonio metro areas continue to expand. Activities associated with urbanization, such as road construction and increased impervious surfaces (surfaces that do not allow infiltration of rain water), can be detrimental to stream habitats (Couch and Hamilton 2002, p. 1). Runoff from increased impervious surfaces increases sediment loads in streams and destabilizes stream channels (Pappas et al. 2008, p. 151). Impervious surfaces also result in channel instability by accelerating stormwater runoff, which increases bank erosion and bed scouring, thereby further increasing downstream sedimentation (Brim Box and Mossa 1999, p. 103). While erosion and sedimentation associated with road construction may be temporary, the existence of road crossings is shown to have ongoing impacts to mussel habitat. For example, in the Guadalupe River, road crossings were found to cause a long-term increase in sedimentation both upstream and downstream, as channel constriction reduced flow upstream, causing sediment deposition, and runoff from the road increased sedimentation downstream (Keen-Zebert and Curran 2009, p. 301). Urban development activities may also affect streams and their mussel fauna where adequate streamside buffers are not maintained and erosion from adjacent land is allowed to enter streams (Brainwood et al. 2006, p. 511).
Large projects that reduce vegetative cover within the watersheds supporting Texas fatmucket populations can also increase sedimentation flowing into streams. For example, the Lower Colorado River Authority Transmission Services Corporation (LCRA TSC) is proposing to construct two new 345- kilovolt (kV) electric transmission line facilities between Tom Green (in the Colorado River basin near San Angelo) and Kendall Counties (in the Guadalupe River basin north of San Antonio) to provide electrical power to accommodate increased human populations (Clary 2010, p. 1). All of the proposed project routes occur within the range of the Texas fatmucket. Two proposed segments would cross through Live Oak Creek, one through the San Saba River, and one through the upper Guadalupe River; all of these streams contain populations of the Texas fatmucket. The proposed project could negatively affect Texas fatmucket habitat if construction or maintenance of the transmission line requires removal of vegetation within the riparian zone and that removal results in an increase in sediment runoff into Live Oak Creek and the Guadalupe and San Saba Rivers (Clary 2010, pp. 7, 9, 15). Similar infrastructure development activities to accommodate

Texas population growth are expected to be undertaken across the species' range and will likely lead to additional sources of sediment in the streams inhabited by the Texas fatmucket.

Streams occupied by Texas fatmucket are subject to increasing levels of sedimentation from agricultural activities, vegetation removal, urbanization, and sand and gravel mining (discussed in section titled Sand and Gravel Mining). All of these activities are ongoing throughout the range of the Texas fatmucket and are unlikely to decrease, resulting in significant threats to the Texas fatmucket.

Dewatering

River dewatering can occur in several ways: Anthropogenic activities such as surface water diversions and groundwater pumping, and natural events, such as drought. Surface water diversions and groundwater pumping can lower water tables, reducing river flows and reservoir levels. When water levels in streams and reservoirs are lowered dramatically, it can result in mussels being stranded and dying in previously wetted areas. This is a particular concern within and below reservoirs where water levels are managed for purposes that result in water levels in the reservoir or downstream to rise or fall in very short periods of time, such as when hydropower facilities release water during peak energy demand periods. Rivers can also be dewatered to expedite construction activities, which happened in the upper Guadalupe River in Kerr County in 1998 for bridge construction; numerous Texas fatmuckets were exposed and desiccated (dried out and died) (Howells 1999, pp. 18–19).

Drought can also severely affect Texas fatmucket populations. For example, near-record dry conditions in 2008, followed by a pattern of below-normal rainfall during the winter and spring of 2009, led to one of the worst droughts in recorded history for most of central Texas, including the range of the Texas fatmucket (Nielsen-Gammon and McRoberts 2009, p. 2). This drought's severity was exacerbated by abnormally high air temperatures, a likely effect of climate change, which has increased average air temperatures in Texas by at least 1 °C (1.8 °F) (Nielsen-Gammon and McRoberts 2009, p. 22). The reservoirs within the Colorado River basin were extremely low during this time due to the drought (Clean Water Action 2011, p. 1), as were river levels. Minimal to no flow was recorded at numerous sites within the basin (U.S. Geological Survey (USGS) 2011a, p. 1). Four of the five current sites of the Texas fatmucket may have had very low flows during the 2009 drought, including populations in the San Saba, Llano, Pedernales, and Guadalupe Rivers (Howells 2010c, pp. 9–10). As low flows persist, mussels face oxygen deprivation, increased water temperature, and, ultimately, stranding (Golladay et al. 2004, p. 501). Only the Llano River has been surveyed since 2009, and the species persists in that river (Burlakova and Karatayev 2011, p. 1).

Central Texas is currently experiencing another extreme drought, with rainfall between October 2010 and July 2011 being the lowest on record during those months (LCRA 2011c, p. 1), and the effects of this drought are being observed but are not yet fully known. As of October 2011, the Llano River has nearly stopped flowing (Mashhood 2011, p. 1); this has undoubtedly affected Texas fatmucket populations in this river. It has also been noted by Burlakova and Karatayev (2012b, p. 14) that sections of the Pedernales River in early 2011 had stopped flowing and only pools of water were left; 65 recently dead Texas fatmucket and other mussels were found as a result of the river drying up (Burlakova and Karatayev 2012b, p. 14).

According to the National Weather Service records for 2011, more than 77 percent of Texas is experiencing moderate to extreme drought (Burlakova and Karatayev 2012b, p. 16). Current climate model simulations suggest that the American southwest could experience a 60-year stretch of heat and drought unseen since the 12th century and that the region is likely to become drier and experience more frequent droughts, with changes accelerating toward the end of the century (Woodhouse et al. 2010, pp. 21283-21288). Droughts result in a decrease in water depth and flow velocity, which reduces food and oxygen delivery. As droughts persist, mussels face hypoxia, elevated water temperature and, ultimately, stranding (Golladay et al. 2004, p. 501).
We do not know the extent of the impacts of stream dewatering on the Texas fatmucket; however, because this species' populations are so small and isolated, the loss of numerous individuals at a site can have dramatic consequences to the population. Hydropower facilities, construction, surface water diversions, groundwater pumping, and drought are occurring throughout the range of the Texas fatmucket; therefore, the effects of dewatering are ongoing and unlikely to decrease in the future, resulting in significant threats to the Texas fatmucket.

Sand and Gravel Mining

Sand and gravel mining (removing bed materials from streams) has been implicated in the destruction of mussel populations across the United States (Hartfield 1993, pp. 136–138). Sand and gravel mining causes stream instability by increasing erosion and turbidity (a measure of water clarity) and causing subsequent sediment deposition downstream (Meador and Layher 1998, pp. 8–9). These changes to the stream can result in large-scale changes to aquatic fauna, by altering habitat and affecting spawning of fish, mussels, and other aquatic species (Kanehl and Lyons 1992, pp. 4–11).

Sedimentation and increased turbidity can accrue from instream mining activities. In the Brazos River, a gravel dredging operation was documented as depositing sediment as far as 1.6 km (1 mi) downstream (Forshage and Carter 1973, p. 697). Accelerated streambank erosion and downcutting of streambeds are common effects of instream sand and gravel mining, as is the mobilization of fine sediments during sand and gravel extraction (Roell 1999, p. 7).

Mining activities may threaten some local Texas fatmucket populations. Currently, one mining operation is permitted near the population in Onion Creek (TPWD 2008c, p. 1), and another in the

Llano River watershed in Kimble County (TPWD 2008a, p. 1). The permits allow for repeated removal of sand and gravel at various instream locations. Two additional mining operations occur in historical habitat for the species—the mainstem Colorado River (U.S. Army

Corps of Engineers (USACE) 2010, p. 2) and Johnson Creek (TPWD 2007a, p. 1).
In areas where repeated mining occurs, an upstream progression of channel degradation and erosion (called headcutting) can occur (Meador and Layher 1998, p. 8). Headcutting may move miles upstream in a zipper-like fashion as the upper boundary of the modified area collapses. Headcutting can be found within the majority of rivers and streams in Texas, including within the Texas fatmucket's current and historical range (Kennon et al. 1967, p. 22). Headcuts induced by sand and gravel mining can cause dramatic changes in streambank and channel shape that may affect instream flow, water chemistry and temperature, bank stability, and siltation (Meador and Layher 1998, p. 8), all of which are harmful to freshwater mussels. Mussels are particularly vulnerable to channel degradation and sedimentation processes associated with headcutting due to their immobility (Pringle 1997, p. 429).

In addition to headcutting, mines that are located near stream channels are subject to the gravel pit being captured by the stream during flood events or due to gradual channel migration (Simmang and Curran 2006, p. 1). For example, two gravel mines along the Colorado River downstream of Austin were inundated; one by stream channel migration in 1984, one by stream capture in 1991 (Simmang and Curran 2006, p. 1). Once captured by the mainstem river, gravel mines contribute large amounts of suspended sediment to the river, causing additional turbidity and sedimentation and further degrading mussel habitat.
Two Texas fatmucket populations in the mainstem Colorado River and Johnson Creek may be currently affected by sand and gravel mining. These activities occur over a long period of time, destabilizing habitat and altering substrates and banks both upstream and downstream. Altered habitat will cause a decrease in the likelihood of recolonization by mussels after the activity has been completed. Therefore, the effects of sand and gravel mining are an ongoing threat to the Texas fatmucket.

Chemical Contaminants
Chemical contaminants are ubiquitous throughout the environment and are a major reason for the decline of freshwater mussel species nationwide (Richter et. al. 1997, p. 1081; Strayer et al. 2004, p. 436; Wang et al. 2007a, p. 2029). Chemicals enter the environment through both point and nonpoint discharges, including spills, industrial sources, municipal effluents, and agriculture runoff. These sources contribute organic compounds, heavy metals, pesticides, herbicides, and a wide variety of newly emerging contaminants to the aquatic environment. As a result, water quality can be degraded to the extent that mussel populations are adversely affected.

Chemical and oil spills can be especially devastating to mussels because they may result in exposure of a relatively immobile species to elevated concentrations that far exceed toxic levels. Acute and chronic exposure to oil spills in freshwater systems is largely understudied; therefore, little information is available on effects of oil spills on freshwater ecosystems (Harrel 1985, p. 223; Bhattacharyya et al. 2002, p. 205). Oil is retained much longer in marshes and other low-energy environments, such as slow-moving streams and rivers, than on wave-swept coasts (Bhattacharyya et al. 2002, p. 205). Oils have been found in sediments at low energy sites as much as 5 years after the occurrence of spills, and they may be released into the water column long after the initial spill. Oil may have various chronic effects on water-column and benthic (bottom-dwelling) species. These effects include sensory disruption, behavioral and developmental abnormalities, and reduced fertility (Bhattacharyya et al. 2002, p. 205). Oil spilled on the water surface may also limit oxygen exchange, coat the gills of aquatic organisms, and cause pathological lesions on respiratory surfaces, thereby affecting respiration in aquatic organisms. Effects of oil on freshwater mussels may result from oil settling on the sediment surfaces and accumulating in the sediment. This can prevent invertebrate colonization (Bhattacharyya et al. 2002, p. 205). Complete recovery of benthic communities may be a matter of years, with communities in the meantime consisting solely of pollutant-tolerant organisms (Bhattacharyya et al. 2002, p. 205). Oil spills can occur from on-site accidents (tank, pipeline spills) or from tanker truck accidents within watersheds occupied by Texas fatmucket. For example, 450 gallons of oil were spilled into Lake Bastrop, a reservoir on a tributary to the Colorado River, in February 2011 (Cihock 2011, p. 1).

Exposure of mussels to persistent low concentrations of contaminants likely to be found in aquatic environments can also adversely affect mussels and their populations. Such concentrations may not be immediately lethal, but over time can result in mortality, reduced filtration efficiency, reduced growth, decreased reproduction, changes in enzyme activity, and behavioral changes to all mussel life stages (Naimo 1995, pp. 351–352; Baun et al. 2008, p. 392). Frequently, procedures that evaluate the ‘‘safe’’ concentration of an environmental contaminant (for example, national water quality criteria) do not have data for freshwater mussel species or do not consider data that are available for freshwater mussels (March et al. 2007, pp. 2066–2067, 2073). One chemical that is particularly toxic to early life stages of mussels is ammonia. Sources of ammonia include agricultural activities (animal feedlots and nitrogenous fertilizers), municipal wastewater treatment plants, and industrial waste (Augspurger et al. 2007, p. 2026), as well as precipitation and natural processes (decomposition of organic nitrogen) (Goudreau et al. 1993, p. 212; Hickey and Martin 1999, p. 44; Augspurger et al. 2003, p. 2569; Newton 2003, p. 2543). Therefore, ammonia is considered a limiting factor for survival and recovery of some mussel species due to its ubiquity in aquatic environments, high level of toxicity, and because the highest concentrations typically occur in mussel microhabitats (Augspurger et al. 2003, p. 2574). In addition, studies have shown that ammonia concentrations increase with increasing temperature and low-flow conditions (Cherry et al. 2005, p. 378; Cooper et al. 2005, p. 381), which may be exacerbated during low-flow events in streams. Within the range of Texas fatmucket, high ammonia levels are common, either chronically, such as in Elm Creek, which is listed as impaired due to high ammonia concentrations (Texas Commission on Environmental Quality (TCEQ) 2010a, p. 294), or due to spills. A wastewater leak in August 2010 spilled approximately 380,000 liters (L) (100,000 gallons (gal)) of sewage into Elm Creek (Bramlette and Cosel 2010, p. 1); ammonia is present in high concentrations in sewage, among other pollutants. Additionally, a sewage spill in 2008 in Onion Creek discharged nearly 380,000 L (100,000 gal), and another sewage spill occurred in April 2011 in Quinlan Creek, a tributary to the Guadalupe River near the Kerr County population (MacCormack 2011, p. 1). High ammonia levels from chronic sources as well as from spills may be affecting Texas fatmucket populations.

In addition to ammonia, agricultural sources of chemical contaminants include two broad categories that have the potential to adversely affect mussel species: Nutrients and pesticides. High amounts of nutrients, such as nitrogen and phosphorus, in streams can stimulate excessive plant growth (algae and periphyton, among others), which in turn can reduce dissolved oxygen levels when dead plant material decomposes. Nutrient over-enrichment in streams is primarily a result of runoff of fertlizer and animal manure from livestock farms, feedlots, and heavily fertilized row crops (Peterjohn and Correll 1984, p. 1471). Over-enriched conditions are exacerbated by low-flow stream conditions, such as those experienced during typical summer season flows. Bauer (1988, p. 244) found that excessive nitrogen concentrations can be detrimental to the adult freshwater pearl mussel (Margaritifera margaritifera), as was evident by the positive linear relationship between mortality and nitrate concentrations. Also, a study of mussel life span and size (Bauer 1992, p. 425) showed a negative correlation between growth rate and high nutrient concentrations, and longevity was reduced as the concentration of nitrates increased. Juvenile mussels in interstitial habitats are particularly affected by depleted dissolved oxygen levels resulting from nutrient over-enrichment (Sparks and Strayer 1998, p. 133). The Texas fatmucket occurs within the Concho River watershed, which has been documented as having particularly high nitrates for nearly 20 years, likely due to intensive agriculture in the area (Texas Clean Rivers Program 2008, p. 2), which may be affecting the Texas fatmucket population.

Mussels are also affected by metals, such as cadmium, chromium, copper, mercury, and zinc, which can negatively affect biological processes such as growth, filtration efficiency, enzyme activity, valve closure, and behavior (Keller and Zam 1991, p. 543; Naimo 1995, pp. 351–355; Jacobson et al. 1997, p. 2390; Valenti et al. 2005, p. 1244). Metals occur in industrial and wastewater effluents and are often a result of atmospheric deposition from industrial processes and incinerators. Studies have shown that copper can have toxic effects on glochidia and juvenile freshwater mussels (Wang et al. 2007a, pp. 2036–2047; Wang et al. 2007b, pp. 2048–2056). In the range of Texas fatmucket, high copper concentrations have been recorded in fish in the lower Guadalupe River and San Antonio River (Lee and Schultz 1994, p. 8). While these high levels of copper in fish are not directly informative of the level of copper within the habitat of the Texas fatmucket, these observations demonstrate that copper levels are likely high in the lower Guadalupe and San Antonio Rivers. Because we know that copper contamination in water can lead to death of mussels, we conclude that the copper may be adversely affecting Texas fatmucket.

Mercury is another heavy metal that has the potential to negatively affect mussel populations, and it is widely distributed in the environment. Mercury has been detected throughout aquatic environments as a product of municipal and industrial waste and atmospheric deposition from coal burning plants. Rainbow mussel (Villosa iris) glochidia have been demonstrated to be more sensitive to mercury than juvenile mussels, with the median lethal concentration value of 14 parts per billion (ppb) for glochidia, compared to 114 ppb for the juvenile life stages (Valenti 2005, p. 1242). The chronic toxicity tests conducted determined that juveniles exposed to mercury greater than or equal to 8 ppb exhibited reduced growth. Acute mercury toxicity was determined to be the cause of extirpation of a diverse mussel community for a 112 km (70 mi) portion of the North Fork Holston River in Virginia (Brown et al. 2005, pp. 1455–1457). Mercury has been documented throughout Texas rivers, with particularly high concentrations in fish in the upper reaches of some of the rivers (Lee and Schultz 1994, p. 8). As with copper, we do not have information on the concentration of mercury that Texas fatmucket is being exposed to in these streams, but the higher than expected levels in fish indicate high mercury levels in the area, which may be adversely affecting Texas fatmucket.

Pesticides are another source of contaminants in streams. Elevated concentrations of pesticides frequently occur in streams due to pesticide runoff, overspray application to row crops, and lack of adequate riparian buffers. The timing of agricultural pesticide applications in the spring often coincides with the reproductive and early life stages of mussels, which may increase the vulnerability of mussels to pesticides (Bringolf et al. 2007a, p. 2094). Little is known regarding the effect of currently used pesticides to freshwater mussels even though some pesticides, such as glyphosate (active ingredient in Roundup®), are used globally. Recent studies tested the toxicity of glyphosate, its formulations, and a surfactant (MON 0810) used in several glyphosate formulations, to early life stages of the fatmucket (Lampsilis siliquoidea) (Bringolf et al. 2007a, p. 2094). Studies conducted with fatmucket juveniles and glochidia determined that the surfactant was the most toxic of the compounds tested and that fatmucket glochidia were the most sensitive organisms tested to date (Bringolf et al. 2007a, p. 2094). Roundup®, technical grade glyphosate isopropylamine salt, and isopropylamine were also acutely toxic to juveniles and glochidia (Bringolf et al. 2007a, p. 2097). These commonly applied pesticides may be adversely affecting Texas fatmucket populations.

The effects of other widely used pesticides, including atrazine, chlorpyrifos, and permethrin, on glochidia and juvenile life stages have also recently been studied (Bringolf et al. 2007b, p. 2101). Environmentally relevant concentrations (concentrations that may be found in streams) of permethrin and chlorpyrifos were found to be toxic to glochidia and juvenile fatmucket (Bringolf et al. 2007b, pp. 2104–2106). Commonly applied pesticides are a threat to mussels as a result of their widespread use. All of these pesticides are commonly used on agricultural lands throughout the range of the Texas fatmucket, which may be adversely affecting the species.

A potential, but undocumented, threat to freshwater mussels, including Texas fatmucket, are compounds referred to as ‘‘emerging contaminants’’ that are being detected in aquatic ecosystems at an increasing rate. These include pharmaceuticals, hormones, and other organic contaminants that have been detected downstream from urban areas and livestock production (Kolpin et al. 2002, p. 1202) and have been shown to affect fish behavior (TCEQ 2010b, p. 3). In samples of the Trinity River, for example, compounds such as antidepressants, antihistamines, blood pressure lowering medication, antiseizure medication, and antimicrobial compounds were all detected during a 2006 study (TCEQ 2010b, pp. 27–28). A large potential source of these emerging contaminants is wastewater being discharged through both permitted (National Pollutant Discharge Elimination System (NPDES)) and nonpermitted sites within the Colorado and Guadalupe River systems. Although streams within the range of Texas fatmucket have not been tested for these emerging contaminants, permitted discharge sites are ubiquitous in watersheds with Texas fatmucket populations, providing many opportunities for contaminants to impact the species.

A study in the Blanco River found that mussels may be adversely affected by sewage effluent (Horne and McIntosh 1979, p. 132). Ammonia levels below the outfall were three times higher than the levels above the outfall and were higher than recently determined toxicity values of ammonia for mussels (Augsperger et al. 2003, p. 2572). The river was nutrient-enriched for miles downstream, and mussels were less abundant below the outfall than above (Horne and McIntosh 1979, pp. 124– 125, 132). Texas fatmucket have not been found alive in the Blanco River since 1978.

Texas Commission on Environmental Quality (TCEQ) data for 2010 indicated that 26 of the 98 assessed water bodies within the within Colorado River basin did not meet surface water quality standards and were classified as impaired water bodies under the Clean Water Act (Texas Clean Rivers Program 2010a, p. 5; 2010b, p. 13), including Elm Creek, due to high ammonia. These water bodies were impaired with dissolved solids, nitrates, bacteria, low dissolved oxygen, aluminum, sulfates, selenium, chloride, and low pH associated with agricultural, urban, municipal, and industrial runoff. Of these, nitrates and low dissolved oxygen pose the greatest threat to Texas fatmucket, as discussed above. Chemical contaminants, such as oil, ammonia, copper, mercury, nutrients, pesticides, and other compounds, are currently a threat to the Texas fatmucket. The species is vulnerable to acute contamination from spills, which have been documented in four of the seven remaining populations, as well as chronic contaminant exposure, which is occurring rangewide.

Summary of Factor A

The reduction in numbers and range of the Texas fatmucket is primarily the result of the long lasting effects of habitat alterations such as the effects of impoundments, sedimentation, dewatering, sand and gravel mining, and chemical contaminants.

Impoundments occur throughout the range of the species and have far reaching effects both up- and downstream. Both the Colorado and Guadalupe River systems have experienced a large amount of sedimentation from agriculture, mining, urban development, and widespread Juniperus ashei removal. Sand and gravel mining affects Texas fatmucket habitat by increasing sedimentation and channel instability downstream and causing headcutting upstream. Finally, chemical contaminants have been documented throughout the range of the species and are significant concern to Texas fatmucket. Based upon our review of the best commercial and scientific data available, we conclude that the present or threatened destruction, modification, or curtailment of its habitat or range is an immediate threat of high magnitude to the Texas fatmucket.

B. Overutilization for commercial, recreational, scientific, or educational purposes:

The Texas fatmucket is not a commercially valuable species and has never been harvested in Texas as a commercial mussel species (Howells 2010c, p. 11), although in the Llano River shells were found that were apparently collected by anglers for use as bait (Howells 1996, p. 22; 2010c, p. 11). Additionally, the Elm Creek population is suspected to have declined in part due to the publication of detailed location information, which may have inspired collectors to visit the site (Howells 2009, pp. 5–6). Scientific collecting is not likely to be a significant threat to the status of the species, although disturbing gravid females can result in glochidial loss and subsequent reproductive failure. Additionally, handling has been shown to reduce shell growth in other mussel species, including several other species of Lampsilis (Haag and Commens-Carson 2008, pp. 505–506). Repeated handling by researchers may adversely affect Texas fatmucket individuals, but these activities are occurring rarely and are not likely to be a threat to populations. Handling for scientific purposes contributes to the long-term conservation of the species. We do not have any evidence of risks to the Texas fatmucket from overutilization for commercial, recreational, scientific, or educational purposes, and we have no reason to believe this factor will become a threat to the species in the future. Based upon the best scientific and commercial information available, we conclude that overutilization for commercial, recreational, scientific, or educational purposes does not pose a significant threat to the Texas fatmucket.

C. Disease or predation:

Disease
Little is known about disease in freshwater mussels. However, disease is believed to be a contributing factor in documented mussel die-offs in other parts of the United States (Neves 1987, pp. 11–12). Diseases have not been documented or observed during any studies of Texas fatmucket.

Predation
Raccoons will prey on freshwater mussels stranded by low waters or deposited in shallow water or on bars following flooding or low water periods (Howells 2010c, p. 12). Predation of Texas fatmucket by raccoons may be occurring occasionally, but there is no indication it is a significant threat to the status of the species.
Some species of fish feed on mussels, such as common carp, freshwater drum, and redear sunfish, all of which are common throughout the range of Texas fatmucket (Hubbs et al. 2008, pp. 19, 45, 53). Common species of flatworms are voracious predators of newly metamorphosed

juvenile mussels of many species (Zimmerman et al. 2003, p. 30). Predation is a normal factor influencing the population dynamics of a healthy mussel population; however, predation may amplify declines in small populations primarily caused by other factors.

Summary of Factor C

Disease in freshwater mussels is poorly known, and we do not have any information indicating it is a threat to the Texas fatmucket. Additionally, while predation is likely occurring within Texas fatmucket populations, it is a natural ecological interaction and we have no information indicating the extent of such predation is large enough to be a threat to populations of Texas fatmucket. Based upon the best scientific and commercial information available, we conclude that disease or predation is not a threat to the Texas fatmucket.

D. The inadequacy of existing regulatory mechanisms:

The Act requires us to examine the adequacy of existing regulatory mechanisms with respect to threats that may place the Texas fatmucket in danger of extinction or increase its likelihood of becoming so in the future. Existing regulatory mechanisms that could affect threats to the Texas fatmucket include State and Federal laws such as the Texas Threatened and Endangered Species regulations, Texas freshwater mussel sanctuaries, State and Federal sand and gravel mining regulations, and regulation of point and non-point source pollution.

Texas Threatened and Endangered Species Regulations

On January 8, 2010, the Texas Parks and Wildlife Commission placed 15 species of freshwater mussels, including the Texas fatmucket, on the State threatened list (Texas Register 2010, pp. 6–10). Section 68.002 of the Texas Parks and Wildlife (TPW) Code and Section 65.171 of the Texas Administrative Code (TAC) prohibit the direct take of a threatened species, except under issuance of a scientific collecting permit. ‘‘Take’’ is defined in Section 1.101(5) of the TPW Code as collect, hook, hunt, net, shoot, or snare, by any means or device, and includes an attempt to take or to pursue in order to take. While this law protects individuals from take, it is difficult to enforce and does not provide any protection for Texas fatmucket habitat. Moreover, our assessment finds that the species is not threatened by take (see Factor B above). There are no State provisions under the Texas Threatened and Endangered Species Regulations for reducing or eliminating the threats (see Factor A above) that may adversely affect Texas fatmucket or its habitat. In addition, these State regulations do not call for development of a recovery plan that will restore and protect existing habitat for the species. For these reasons, we find that existing Texas regulatory mechanisms for State-listed threatened species are currently inadequate to protect Texas fatmucket and its habitat or to prevent further decline of the species.

Freshwater Mussel Sanctuaries

The TPWD has designated specific areas of streams and reservoirs as no harvest mussel sanctuaries (31 TAC, part 2, chapter 57, subpart B, Rule 57.157). The locations of the designated mussel sanctuaries were selected because they support populations of rare and endemic mussel species or are important for maintaining, repopulating, or allowing recovery of mussels in watersheds where they have been depleted. As a result of the designation of mussel sanctuaries, four of the Texas fatmucket populations are protected from harvesting disturbance of other species (Howells 2010f, p. 12). Unfortunately, mussel sanctuaries only restrict the harvest of mussels and do not address other activities that may affect mussels or their habitats. Therefore, these designations provide no regulatory mechanisms to protect Texas fatmucket from habitat alteration.

State Sand and Gravel Mining Regulations

TPWD has been responsible for regulating the ‘‘disturbance of taking’’ streambed materials since 1911 (Meador and Layher 1998, p. 11) and has issued several permits for ongoing activities within the Texas fatmucket range (for more information on the effects of sand and gravel mining on Texas fatmucket, please refer to ‘‘Sand and Gravel Mining’’ under Factor A in Five-Factor Evaluation). In addition to authorized activities, there are ongoing unauthorized sand and gravel mining activities within the range of Texas fatmucket. For example, the LCRA, which monitors water quality permit applications submitted through other agencies (LCRA 2011b, p. 1), found unpermitted sand removal from the Llano River in Llano County during a site visit in 2010 (Lehman 2010, p. 1). This site is located upstream from a known population of the Texas fatmucket and other rare mussels (Howells 1994, p. 6), and the sand removal may have increased turbidity and sedimentation downstream within Texas fatmucket habitat. Sand and gravel mining may be one of the least regulated of all mining activities (Meador and Layher 1998, p. 10).

Clean Water Act

The U.S. Army Corps of Engineers (USACE) retains oversight authority and requires a permit for gravel and sand mining activities that deposit fill into streams under section 404 of the Clean Water Act (33 U.S.C. 1251 et seq.). Additionally, a permit is required under section 10 of the Rivers and Harbors Act (33 U.S.C. 401 et seq.) for navigable waterways. However, many mining operations do not fall under these two categories. For example, nationwide permits are issued by the USACE for types of projects that are presumed to have minimal environmental impacts. However, projects permitted by nationwide permits, such as small mining operations, may have cumulative effects on aquatic species like the Texas fatmucket through increased sedimentation and channel instability.

Point source discharges of potential contaminants within the range of the Texas fatmucket have been reduced since the inception of the Clean Water Act, but this reduction may not provide adequate protection for filter-feeding organisms that can be affected by extremely low levels of contaminants (see ‘‘Chemical Contaminants’’ under Factor A). The EPA’s established water quality criteria may not be protective of mussels. Current water quality standards applied by EPA were established to be protective of aquatic life; however, freshwater mussels were not used to develop these standards (EPA 2005, p. 5), and current research reveals mussels to be more sensitive to many aquatic pollutants than the tested organisms (Augsperger et al. 2007, p. 2025). For example,

Augspurger et al. (2003, p. 2572) and Sharpe (2005, p. 28) suggested that the criteria for ammonia may not be sufficient to prevent impacts to mussels under current and future climate conditions. In addition, chronic copper concentrations lethal to juvenile freshwater mussels have been shown to be less than the EPA's 1996 chronic water quality criterion for copper (Wang et al. 2007b, pp. 2052–2055). Based on this information, the existing EPA water quality criteria may not be sufficient to prevent negative effects to the Texas fatmucket.
Nonpoint source pollution such as sedimentation and chemical contamination is considered a significant threat to Texas fatmucket habitat; however, the Clean Water Act does not adequately protect Texas fatmucket habitat from nonpoint source pollution, because most activities that cause nonpoint source pollution are not regulated under the Clean Water Act.

Summary of Factor D
Despite some State and Federal laws protecting the species and water quality, the Texas fatmucket continues to decline due to the effects of habitat destruction, poor water quality, contaminants, and other factors. The regulatory measures described above are not sufficient to significantly reduce or remove the threats to the Texas fatmucket. Based upon our review of the best commercial and scientific data available, we conclude that the lack of existing regulatory mechanisms is an immediate threat of moderate magnitude to the Texas fatmucket.

E. Other natural or manmade factors affecting its continued existence:

Natural and manmade factors that threaten the Texas fatmucket include climate change, population fragmentation and isolation, and nonnative species.

Climate Change
It is widely accepted that changes in climate are occurring worldwide (International Panel on Climate Change (IPCC) 2007, p. 30). Understanding the effects of climate change on the Texas fatmucket is important because the disjunct nature of the remaining Texas fatmucket populations, coupled with the limited ability of mussels to migrate, makes it unlikely that the Texas fatmucket can adjust its range in response to changes in climate (Strayer 2008, p. 30). For example, changes in temperature and precipitation can increase the likelihood of flooding or increase drought duration and intensity, resulting in direct effects to freshwater mussels like the Texas fatmucket (Hastie et al. 2003, pp. 40–43; Golloday et al. 2004, p. 503). Because the range of the Texas fatmucket has been reduced to isolated locations with low population numbers in small to medium sized rivers and streams, the Texas fatmucket is vulnerable to climatic changes that could decrease the availability of water or produce more frequent scouring flood events. Indirect effects of climate change may include declines in host fish populations, habitat reduction, and changes in human activity in response to climate change (Hastie et al. 2003, pp. 43–44).

For the next two decades, a warming of about 0.2 °C (0.4 °F) per decade is projected across the United States (IPCC 2007, p. 12), and hot extremes, heat waves, and heavy precipitation and flooding are expected to increase in frequency (IPCC 2007, p. 18). As with many areas of North America, central Texas is projected to experience an overall warming trend in the range of 2.5 to 3.3 °C (4.5 to 6 °F) over the next 50 to 200 years (Mace and Wade 2008, p. 656). Even under lower greenhouse gas emission scenarios, recent projections forecast a 2.8 °C (5 °F) increase in temperature and a 10 percent decline in precipitation in central Texas by 2080–2099 (Karl et al. 2009, pp. 123–124). Based on our current understanding of climate change, air temperatures are expected to rise and precipitation patterns are expected to change in areas occupied by the Texas fatmucket. Karl et al. (2009, p. 12) also suggests that climate change impacts on water resources in the southern Great Plains (including central Texas) are expected as rising temperatures and decreasing precipitation exacerbate an area already plagued by low rainfall, high temperatures, and unsustainable water use practices.

One preliminary study forecasting the possible hydrological impacts of climate change on the annual runoff and its seasonality in the upper Colorado River watershed was conducted by CH2M HILL (2008). In this initial evaluation, four modeling scenarios (chosen to represent a range of possible future climatic conditions) were each run under a 2050 and 2080 time scenario, producing annual surface water runoff estimates at multiple sites with stream gages in the Colorado River basin. For the 2050 scenarios, the results from all four climate change scenarios predicted significant decreases in annual runoff totals compared to historic averages (CH2M HILL 2008, pp. 7–30—7–32). For the 2080 scenarios, one model predicted increases in annual runoff; the other three 2080 scenarios predicted decreases in annual runoff (CH2M HILL 2008, pp. 7–30—7–33). The modeling efforts from this study focus on annual averages and cannot necessarily account for the seasonal variations in flooding events or long periods of drought. However, the study demonstrates the potential effects of climate change on surface water availability, which is forecasted to result in an overall decline in stream flows in the region where the Texas fatmucket occurs.

In summary, climate change could affect the Texas fatmucket through the combined effects of global and regional climate change, along with the increased probability of long-term drought. Climate change exacerbates threats such as habitat degradation from prolonged periods of drought, increased water temperature, and the increased allocation of water for municipal, agricultural, and industrial use. As such, climate change, in and of itself, may affect the Texas fatmucket, but the magnitude and imminence (when the effects occur) of the effects remain uncertain. Based upon our review of the best commercial and scientific data available, we conclude that the effects of climate change in the future will likely exacerbate the current and ongoing threats of habitat loss and degradation caused by other factors, as discussed above.

Population Fragmentation and Isolation

All of the remaining populations of the Texas fatmucket are small and geographically isolated and thus are susceptible to genetic drift (change of gene frequencies in a population over time), inbreeding depression, and random or chance changes to the environment, such as toxic chemical spills (Watters and Dunn 1995, pp. 257– 258) or dewatering. Inbreeding depression can result in death, decreased fertility, smaller body size, loss of vigor, reduced fitness, and various chromosomal abnormalities (Smith 1974, pp. 350). Despite any evolutionary adaptations for rarity, habitat loss and degradation increase a species' vulnerability to extinction (Noss and Cooperrider 1994, pp. 58–62). Numerous authors (including Noss and Cooperrider 1994, pp. 58–62; Thomas 1994, p. 373) have indicated that the probability of extinction increases with decreasing habitat availability. Although changes in the environment may cause populations to fluctuate naturally, small and low-density populations are more likely to fluctuate below a minimum viable population (the minimum or threshold number of individuals needed in a population to persist in a viable state for a given interval) (Gilpin and Soule 1986, pp. 25–33; Shaffer 1981, p. 131; Shaffer and Samson 1985, pp. 148– 150).

The Texas fatmucket was widespread throughout much of the Colorado and Guadalupe River systems when few natural barriers existed to prevent migration (via host species) among suitable habitats. Construction of dams, however, likely destroyed many Texas fatmucket populations through drastic habitat changes and isolated the remnant populations from each other. For fertilization, Texas fatmucket females need an upstream male to release sperm; populations with few individuals reduce the likelihood that females will be exposed to sperm while siphoning. Therefore, recruitment failure is a potential problem for many small populations rangewide, a potential condition exacerbated by its reduced range and increasingly isolated populations. If downward population trends continue, further significant declines in total Texas fatmucket population size and consequent reduction in long-term survivability may soon become apparent. The small, isolated nature of the Texas fatmucket's remaining populations also increases the species' vulnerability to stochastic (random) natural events. When species are limited to small, isolated habitats, as the Texas fatmucket is, they are more likely to become extinct due to a local event that negatively effects the population (McKinney 1997, p. 497; Minckley and Unmack 2000, pp. 52–53; Shepard 1993, pp. 354–357). While the populations' small, isolated nature does not represent an independent threat to the species, it does substantially increase the risk of extirpation from the effects of all other threats, including those addressed in this analysis, and those that could occur in the future from unknown sources.

Based upon our review of the best commercial and scientific data available, we conclude that fragmentation and isolation of small remaining populations of the Texas fatmucket exacerbate ongoing threats to the species throughout all of its range and are expected to continue.

Nonnative Species

Various nonnative species of aquatic organisms are firmly established within the range of the Texas fatmucket and pose a threat to the species. Golden algae (Prymnesium parvum) is a microscopic algae considered to be one of the most harmful algal species to fish and other gill-breathing organisms (Lutz-Carrillo et al. 2010, p. 24). Golden algae was first discovered in Texas in 1985 and is presumed to have been introduced from western Europe (Lutz- Carrillo et al.

2010, p. 30). Since its introduction, golden algae has been found in Texas rivers and lakes, including two lakes in central Texas (Baylor University 2009, p. 1). Under certain environmental conditions, this algae can produce toxins that can cause massive fish and mussel kills (Barkoh and Fries 2010, p. 1; Lutz-Carrillo et al. 2010, p. 24). Evidence shows that golden algae probably caused fish kills in Texas as early as the 1960s, but the first documented fish kill due to golden algae in inland waters of Texas occurred in 1985 on the Pecos River in the Rio Grande basin (TPWD 2002, p. 1). The range of golden algae has increased to include portions of the Brazos and Colorado River basins, among others, and it has been responsible for killing more than 8 million fish in the Brazos River since 1981 and more than 2 million fish in the Colorado River since 1989 (TPWD 2010a, p. 1). Although actual mussel kills in Texas due to golden algae have not been recorded in the past, the toxin can kill mussels. Therefore, the elimination of host fish and the poisonous nature of the toxin to mussels make future golden algae blooms a threat to the Texas fatmucket.

An additional nonnative species, the zebra mussel (Dreissena polymorpha), poses a potential threat to the Texas fatmucket. This invasive species has been responsible for the extirpation of freshwater mussels in other regions of the United States, including the Higgin’s eye (Lampsilis higginsii) in Wisconsin and Iowa (Service 2006, pp. 9–10). Zebra mussels attach in large numbers to the shells of live native mussels and are implicated in the loss of entire native mussel beds (Ricciardi et al. 1998, p. 615). This fouling impedes locomotion (both laterally and vertically), interferes with normal valve movements, deforms valve margins, and essentially suffocates and starves the native mussels by depleting the surrounding water of oxygen and food (Strayer 1999, pp. 77–80). Heavy infestations of zebra mussels on native mussels may overly stress the animals by reducing their energy reserves. Zebra mussels may also filter the sperm and possibly glochidia of native mussels from the water column, thus reducing reproductive potential. Habitat for native mussels may also be degraded by large deposits of zebra mussel pseudofeces (undigested waste material passed out of the incurrent siphon) (Vaughan 1997, p. 11).

Zebra mussels are not currently found within the range of the Texas fatmucket. However, a live adult zebra mussel was first documented in Lake Texoma on the Red River (on the north Texas border with Oklahoma) in 2009 (TPWD 2009a, p. 1). Since that time, additional zebra mussels have been reported from Lake Texoma, where they are now believed to be well established (TPWD 2009c, p. 1). In spring and summer of 2013, Texas Parks and Wildlife Department (TPWD) monitored 23 other Texas reservoirs and found that zebra mussels may be present in two additional reservoirs: Lake Worth and Joe Pool. No adult zebra mussels or veligers have been found in either of the aforementioned water bodies (TPWD 2013, p. 1). To date, Lake Texoma, Lake Ray Roberts, Lake Lewisville, Lake Bridgeport, Lake Lavon, Lake Belton, and Lake Waco reservoirs and Elm Fork of the Trinity River are known to harbor zebra mussels TPWD 2014, p. 1). Zebra mussels are likely to spread to many other Texas reservoirs through accidental human transport (Schneider et al. 1998, p. 789). Although zebra mussels tend to proliferate in reservoirs or large pools, released zebra mussel veligers float downstream and attach to any hard surface available, rendering downstream Texas fatmucket populations extremely vulnerable to attachment and fouling. Because zebra mussels are so easily introduced to new locations, the potential for zebra mussels to continue to expand in Texas and invade the range of the Texas fatmucket is high.

If this occurs, the Texas fatmucket is vulnerable to zebra mussel attachment and subsequent deprivation of oxygen, food, and mobility.

A molluscivore (mollusk eater), the black carp (Mylopharyngodon piceus) is a potential threat to the Texas fatmucket. The species has been commonly used by aquaculturists to control snails or for research in fish production in several States, including Texas (72 FR 59019, October 18, 2007). Black carp can reach more than 1.3 m (4 ft) in length and 150 pounds (68 kilograms (kg)) (Nico and Williams 1996, p. 6). Foraging rates for a 4-year old fish average 3 to 4 pounds (1.4 to1.8 kg) a day, indicating that a single individual could consume 10 tons (9,072 kg) of native mollusks over its lifetime (Mississippi Interstate Cooperative Resource Association (MICRA) 2005, p. 1). Black carp can escape from aquaculture facilities. For example, in 1994 30 black carp escaped from an aquaculture facility in Missouri during a flood. Other escapes into the wild by non-sterile carp are likely to occur. Because of the high risk to freshwater mussels and other native mollusks, the Service recently listed black carp as an injurious species under the Lacey Act (72 FR 59019, October 18, 2007), which prevents importations and interstate transfer of this harmful species, but does not prevent its release into the wild once it is in the State. If the black carp were to escape within the range of the Texas fatmucket, it would likely negatively affect native mussels, including the Texas fatmucket.

Based upon our review of the best commercial and scientific data available, we conclude that golden algae is an ongoing threat to the Texas fatmucket, and other nonnative species, such as zebra mussels and black carp, are a potential future threat to the Texas fatmucket that is likely to increase as these exotic species expand their occupancy within the range of the Texas fatmucket.

Summary of Factor E
The effects of climate change, while difficult to quantify at this time, are likely to exacerbate the current and ongoing threat of habitat loss caused by other factors, and the small sizes and fragmented nature of the remaining populations render them more vulnerable to extirpation. In addition, nonnative species, such as golden algae, currently threaten the Texas fatmucket, and the potential introduction of zebra mussels and black carp are potential future threats. Based upon our review of the best commercial and scientific data available, we conclude that other natural or manmade factors are immediate threats of moderate magnitude to the Texas fatmucket.

Conservation Measures Planned or Implemented :

The Texas fatmucket is listed as threatened by the TPWD in Texas and is a high priority species in the Texas Wildlife Action Plan 2005-2010 (TPWD 2005, p. 756). The Service, TPWD, academia, and other resource agencies have proposed and ongoing studies in Texas’ river systems for Texas freshwater mussels, including the Texas fatmucket, observing life history parameters (including determination of ecological fish hosts), survivability of juveniles, monitoring habitat, and analyzing population dynamics. In addition, TPWD has established a Mussel Watch group.

The Service is currently working on forming and implementing the use of a Strategic Conservation Plan for Texas Freshwater Mussels that will result in additional conservation measures such as, best management practices, survey protocols, relocation protocols, and monitoring guidelines. The Service will be collaborating with other Federal, State, and non-governmental agencies during the formation and implementation of the Strategic Conservation Plan.

Summary of Threats :

This status review identified threats to the Texas fatmucket attributable to Factors A, D, and E. The primary threat to the species is from habitat destruction and modification (Factor A) from impoundments, which scour riverbeds, thereby removing mussel habitat, decrease water quality, modify stream flows, and prevent fish host migration and distribution of freshwater mussels, as well as sedimentation, dewatering, sand and gravel mining, and chemical contaminants. Additionally, most of these threats may be exacerbated by the current and projected effects of climate change (discussed in Factor E). Threats to the Texas fatmucket and its habitat are not being adequately addressed through existing regulatory mechanisms (Factor D). Because of the limited distribution of this endemic species and its lack of mobility, these threats are likely to result in the extinction of the Texas fatmucket in the foreseeable future.

The Texas fatmucket has been added as a candidate because it was found to warrant listing; however, it has been precluded by higher priority listing actions, and progress is being made to add or remove qualified species from the Lists of Endangered and Threatened Wildlife and Plants.

For species that are being removed from candidate status:

_____ Is the removal based in whole or in part on one or more individual conservation efforts that you determined met the standards in the Policy for Evaluation of Conservation Efforts When Making Listing Decisions(PECE)?

Recommended Conservation Measures :

Continued survey and monitoring efforts are needed throughout former and occupied sites to better define the species’ distribution and status in the Colorado and Guadalupe-San Antonio River systems.

Continued biological and ecological research efforts are needed to identify host fish, spawning and brooding seasons, glochidia, and habitat and physiochemical parameters for Texas fatmucket.
The Service will continue to work with TPWD, United States Geological Surveys (USGS), and

others needed research in order to facilitate the conservation and preservation of the Texas fatmucket.

Long-term conservation measures need to be developed to facilitate and accomplish cooperative efforts between resource management agencies and private landowners. The development of candidate conservation agreements (with assurances) with interested parties would initiate conservation for the Texas fatmucket.

The Service will continue working with resource management agencies and the Texas Department of Transportation (TxDOT) on developing best management practices for proposed adjacent/instream impacts specific to Texas water systems.

The Service will continue working with resource management agencies and academia on developing a drought contingency plan that will facilitate the management and monitoring of mussel populations that harbor species of concern (i.e. the Texas fatmucket) during times of drought.

The Service will continue working with resource management agencies, TxDOT, and academia on the development of standard mussel survey, relocation, and monitoring protocols, which would establish a commonality among the wide variety of methods currently being used in Texas and would establish a baseline of what kind of data needs to be collected while conducting surveys.

Priority Table

Magnitude	Immediacy	Taxonomy	Priority
High	**Imminent**	Monotypic genus	1
		Species	**2**
		Subspecies/Population	3
	Non-imminent	Monotypic genus	4
		Species	5
		Subspecies/Population	6
Moderate to Low	Imminent	Monotype genus	7
		Species	8
		Subspecies/Population	9
	Non-Imminent	Monotype genus	10
		Species	11
		Subspecies/Population	12

Rationale for Change in Listing Priority Number:

No change in listing priority number.

Magnitude:

We consider the threats that the Texas fatmucket faces to be high in magnitude. Habitat loss and degradation from impoundments, sedimentation, sand and gravel mining, and chemical contaminants are widespread throughout the range of the Texas fatmucket and profoundly affect its survival and recruitment. Remaining populations are small, isolated, and highly vulnerable to stochastic events.

Imminence :

We consider the threats to the Texas fatmucket as described under Factors A, D, and E in the Five-Factor Evaluation for Texas Fatmucket section to be imminent because these threats have affected the species in the past, are ongoing, and will continue in the foreseeable future. Habitat loss and destruction have already occurred and will continue as the human population continues to grow in central Texas. Texas fatmucket populations may already be below the minimum viable population requirement, which would cause a reduction in the number of populations and an increase in the species’ vulnerability to extinction. These threats are exacerbated by climate change, which will increase the frequency and magnitude of droughts. Therefore, we consider these threats to be imminent.

__Yes__ Have you promptly reviewed all of the information received regarding the species for the purpose of determination whether emergency listing is needed?

Emergency Listing Review

__No__ Is Emergency Listing Warranted?

Description of Monitoring:

The TPWD Mussel Watch group has been conducting surveys throughout Texas and found several fresh dead Texas fatmucket in the Colorado and Guadalupe-San Antonio River systems. The groups continued efforts along with historic data has sparked the interest of academia to further survey efforts in the Colorado and Brazos River systems where a couple of large, stable, reproducing populations were discovered and are now being closely monitored. These recent discoveries will likely lead to increased survey and monitoring efforts throughout Texas.

Indicate which State(s) (within the range of the species) provided information or comments on the species or latest species assessment:

none

Indicate which State(s) did not provide any information or comment:

none

State Coordination:

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Approval/Concurrence:

Lead Regions must obtain written concurrence from all other Regions within the range of the species before recommending changes, including elevations or removals from candidate status and listing priority changes; the Regional Director must approve all such recommendations. The Director must concur on all resubmitted 12-month petition findings, additions or removal of species from candidate status, and listing priority changes.

Approve: 06/12/2015
Date

Concur: 12/15/2015
Date

Did not concur: ____________________ ________
Date

Director's Remarks: